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(54) Abstract Title

Fluid pressure sensor with three SAW devices

(57) A pressure (eg tyre pressure) monitor 1 has a container 4 with a base 3A,3B and a lid 5 secured to the base to define a fluid tight chamber 6. At least part of the lid 5 is flexible and acts as a diaphragm 5A which deflects in response to an applied pressure. A projection 10 is provided on the diaphragm 5A which transmits movement of the diaphragm to a SAW device Y on a substrate 7. Further SAW devices X,Z are mounted within the chamber 6 and one of these Z is located at a different angle (eg 10° to 30°) to the others on a region of the substrate (or on a separate substrate) which does not deform when the pressure is applied. The measurements from the three SAW devices provide a pressure measurement which compensates for changes in operating pressure.

Fig.1A.

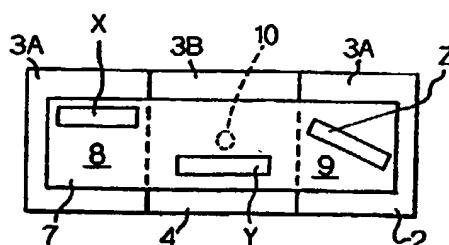
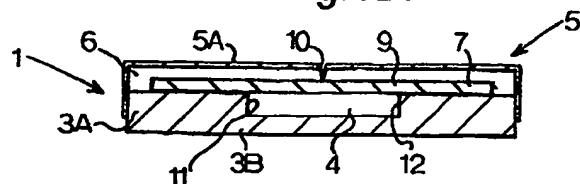


Fig.1B.



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Fig.1A.

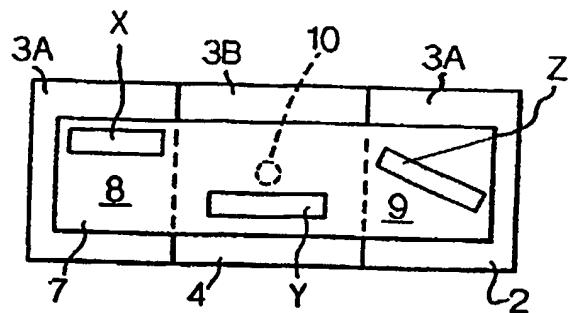


Fig.1B.

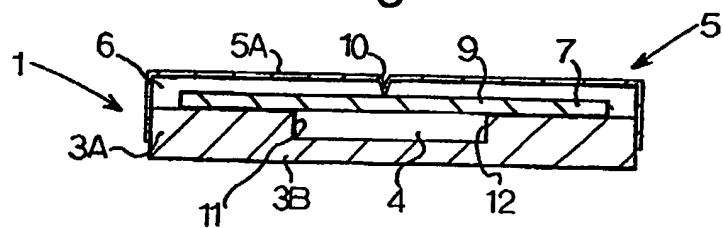


Fig.2A.

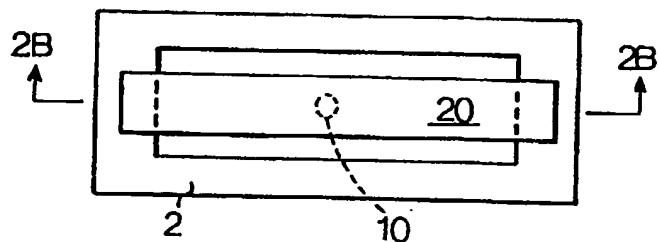
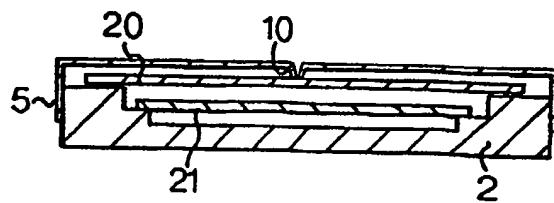


Fig.2B.



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Fig.3A.

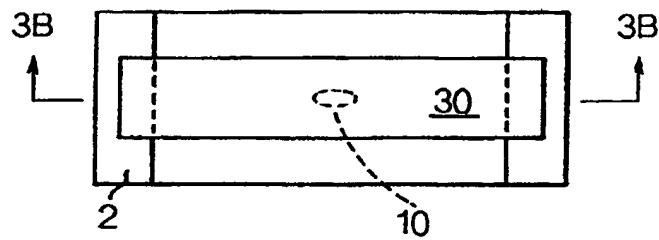


Fig.3B.

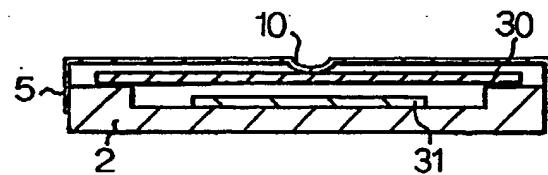


Fig.4A.

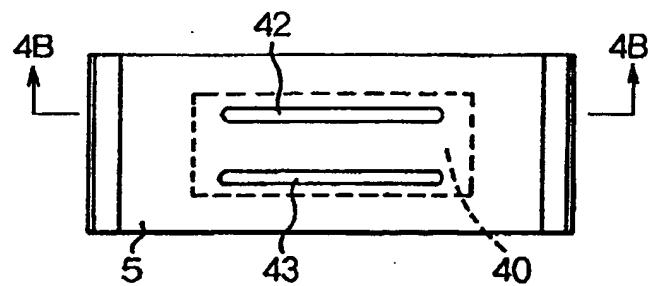
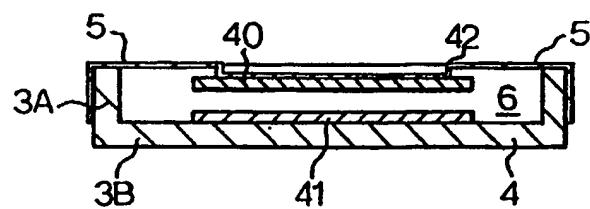


Fig.4B.



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FIG. 5A

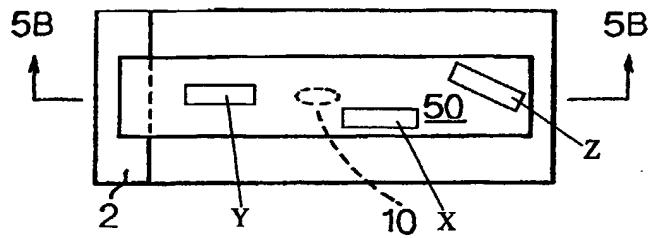


FIG. 5B

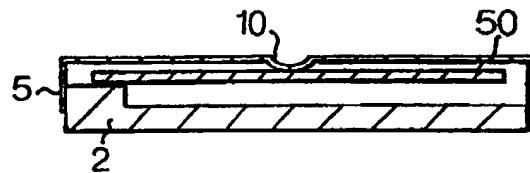


FIG. 6A

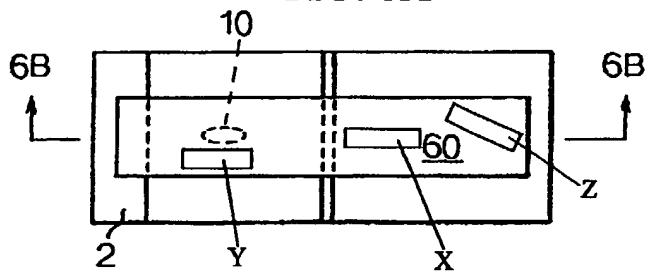
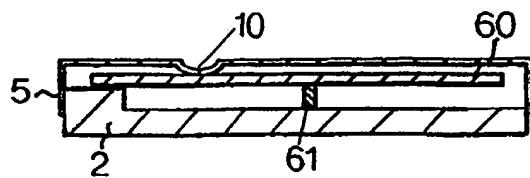


FIG. 6B



PRESSURE MONITOR INCORPORATING SAW DEVICE

This invention relates to a pressure monitor incorporating a SAW device.

Pressure monitors incorporating SAW devices have been proposed, for example in our United Kingdom patent application GB-A-2352814. The SAW devices are used to produce an electrical signal indicative of the position of a pressure sensitive member, for example a diaphragm, which is used to divide a chamber containing a reference pressure from a chamber which is subject to a variable pressure. The present invention relates to an improved pressure monitor of this type.

GB 2235533 discloses a piezoelectric sensor device in which a surface acoustic wave device is mounted on a flexible diaphragm which is supported around its periphery by an integral rigid assembly. Displacement of the diaphragm, for example in response to an applied pressure, induces a strain in the piezoelectric material thus causing a corresponding change in the characteristic frequency of the SAW device. These changes in the characteristic frequency of the SAW device are, then, used as a measure of the deflection of the diaphragm and hence of the pressure applied thereto. This device has the advantage that, by mounting the SAW device on the diaphragm, the device is very sensitive. However, mechanical edge effects associated with clamping the edge of the diaphragm considerably complicate interpreting the signal receiver from the SAW device. Furthermore, variations in temperature will cause variations in the characteristic frequency of the SAW device which will effect the accuracy of the device.

In accordance with the first aspect of the present invention there is provided a pressure monitor comprising a base having a rigid frame; a lid secured to the base to define with the base a substantially fluid tight chamber, at least part of the lid being flexible and forming a diaphragm which will deflect in response to changes in the fluid pressure surrounding the monitor; means remote from the edge of the frame for transmitting movement of the diaphragm to a distortable substrate located within the chamber, the distortable substrate having a first SAW device mounted thereon, and at

least a second and a third SAW device mounted within the chamber, said second SAW device being carried on a reference substrate section and having its direction of propagation inclined at an angle to the direction of propagation of at least one of said first and third SAW devices, wherein movement of the diaphragm induced by a change in pressure in the zone surrounding the monitor results in distortion of the distortable substrate, which is measurable by the SAW device mounted thereon, without distorting said reference substrate section.

The SAW devices may be of the resonator type in which case the distortion of the SAW device may be measured by measuring the change in resonant frequency produced by the distortion, or may be of the delay line type in which case the distortion of the SAW device may be measured by measuring the change in delay characteristics produced by the distortion. Accordingly, changes in the pressure to which the monitor is subjected may be determined by observing the changes in the characteristics of the SAW device.

In a particularly preferred embodiment of the invention the SAW device is supported by the frame and extends along the length of the chamber enclosed by the rigid frame and the lid. Accordingly, deflection of the lid acting as a diaphragm will cause bending of the SAW device with a resulting change in output of the SAW device.

By providing three SAW resonator devices having different resonance frequencies, by analysis of the frequency shifts produced by distortion of one of the SAW devices a temperature compensated indication of the distortion of the SAW device and accordingly the displacement of the diaphragm may be obtained, together with an indication of temperature of the SAW device. The three SAW devices may be located on the same side of a common substrate or two may be located on one side of a common substrate and the other located on the opposite side of the common substrate. Alternatively, two individual substrates, one carrying two SAW devices (on the same or respective opposite sides thereof) and one carrying one SAW device may be provided. If more than one substrate is provided the arrangement should be such

that one SAW device is subjected to strain from the deflexion of the lid and the other two SAW devices are unstrained providing references for pressure and temperature measurement. The orientation of one of the unstrained SAW devices is at a non-zero angle to the propagation direction of the other unstrained SAW device to provide unambiguous temperature information.

In the preferred embodiment of the invention the means remote from the edge of the frame for transmitting movement of the diaphragm to the SAW device comprises one or more bumps provided on the lid which can press on the substrate of a SAW device but which cannot exert a pulling force on the SAW device. The or each bump may be provided by a depression formed in the material of the lid or by means of a suitable member secured to the lid.

In one embodiment, the chamber is hermetically sealed with a reference pressure. The reference pressure is selected so that when the device is located within the zone in which it is to operate, the pressure surrounding the device is higher than the reference pressure with a result that the diaphragm will deflect inwardly of the base and exert a force on one of the SAW devices.

Preferably, the base is a ceramic or metal base to which the lid is secured.

In one embodiment of the invention a single sided SAW device is mounted face down supported by the base with the diaphragm bump pressing from the back and a second substrate is mounted in an unstrained area and carries the two reference SAW devices (one for pressure and one for temperature). According to a further embodiment of the invention a double sided SAW device is used to detect pressure transmitted by two bumps and the reference SAW devices are mounted in an unstrained location in the chamber for temperature and pressure reference information.

At least three SAW devices, one inclined with respect to at least one of the others, are required so that both temperature and pressure measurements can be attained. Two of the SAW devices may be respectively mounted on one side of two substrates, or two of them may be mounted on the opposite sides of one substrate. If

two substrates are provided, the lid preferably includes three indentations whereby the two substrates may each be supported along one edge by a common ridge and along an opposite edge by a respective ridge. Preferably, the substrates extend side by side along the lid.

The devices may be arranged so that two are strained and one is unstrained. Two strained SAW devices are then arranged so that one is deformed in compression and one being deformed in tension by movement of the lid. The SAW devices may be laid down on the opposite sides of a common substrate or on separate substrates. If separate substrates are used they should be arranged so that simultaneously one SAW device is deformed in compression and one SAW device is deformed in tension.

Preferably, the lid acting as a diaphragm a metal alloy, for example an iron, cobalt, nickel alloy. For example the lid may be of Kovar. The base is preferably of a metal alloy (for example Kovar) but may be of any suitable material, for example a ceramic material.

The invention will be better understood from the following description of preferred embodiments thereof, given by way of example only, reference being had to the accompanying drawings wherein:

Figure 1A is a schematic view of a first embodiment of the invention before application of the lid;

Figure 1B is a schematic cross sectional view of the first embodiment of the invention along the line 1B-1B of Fig 1A, with the lid in place;

Figure 2A is a schematic view corresponding to Fig 1A, but showing a second embodiment of the invention;

Figure 2B is a schematic cross sectional view of the second embodiment of the invention along the line 2B-2B of Fig 2A, with the lid in place;

Figure 3A is a schematic view corresponding to Fig 1A, but showing a third embodiment of the invention;

Figure 3B is a schematic cross sectional view of the third embodiment of the invention along the line 3B-3B of Fig 3A, with the lid in place;

Figure 4A is a schematic plan view showing a fourth embodiment of the invention;

Figure 4B is a schematic cross sectional view of the fourth embodiment of the invention along the line 4B-4B of Fig 4A.

Figure 5A is a schematic plan view showing a fifth embodiment of the invention;

Figure 5B is a schematic cross sectional view of the fifth embodiment along the line 5B-5B of Figure 5A;

Figure 6A is a schematic plan view showing a sixth embodiment of the invention; and

Figure 6B is a schematic cross sectional view of the sixth embodiment along the line 6B-6B of Figure 6A.

Referring firstly to Figures 1A and 1B, there is shown schematically a pressure monitor 1 comprising a base 2 having rigid frame 3A and a rigid base 3B which together define a shallow rectangular container 4. The container 4 may be formed of any suitable material, and in the preferred embodiment of the invention is formed of a metal material, for example Kovar. The container 4 has secured to the open end thereof a lid 5 having a major surface 5A acting as a diaphragm. The lid may be of any suitable material, for example Kovar. Both the material from which the base is made and the material from which the lid acting as a diaphragm is made are preferably impermeable to gas and the seal between the lid and the base is also preferably impermeable to gas. The seal between the lid in the base may be formed by any convenient means. If both the lid and the base are of suitable metal alloys the seal therebetween may be formed by a soldering process. When the lid 5 acting as a diaphragm is secured to the base 4 a sealed chamber 6 is defined by the lid and the base. The absolute pressure contained within the chamber 6 is determined at the time of manufacture in light of the pressure conditions to which the device is to be sensitive. If, for example, the device is intended to monitor the pressure within a vehicle tyre it will typically operate within a zone having pressure of two to ten bar

and under these circumstances the pressure sealed within the chamber 6 may, for example be one bar at a temperature of 20°C. Alternatively, a vacuum may be sealed in the chamber 6 to provide absolute pressure readings.

Mounted within the chamber 6 is a single substrate 7 which has formed thereon three SAW devices X, Y, Z, to provide a temperature compensated pressure and temperature monitoring output. The SAW devices may, for example, be SAW resonators having different resonant frequencies so that the changes in the resonant frequencies of the respective SAW devices may be determined using existing conventional SAW device interrogating technology.

The advantage of this arrangement is that the SAW devices X and Z remain unstrained and only the SAW device Y is strained when the pressure is applied to the sensor. This considerably simplifies the process of sensor calibration and calculation of pressure and temperature from the results of frequency measurements.

Indeed, the measured difference between the two resonant frequencies, $|f_x - f_z|$ depends only on temperature, not on pressure, so the value of the temperature can be immediately found from $|f_x - f_z|$. Since both the devices X and Z are fabricated on the same substrate the frequency difference $|f_x - f_z|$ will depend on the temperature only in the case if the temperature characteristic of the device Z differs from that of the device X. In order to achieve such a differing temperature characteristic, the device Z is rotated relative to the device X at a certain angle as shown in Fig 1A. The temperature sensitivity depends on the rotation angle. An angle is in the range of 10-30°, in particular 16-20° has been found to achieve particularly good results. For example, an angle of 18° gives the sensitivity of approximately $2 \text{ kHz}^{\circ}\text{C}^{-1}$ for the ST-X cut quartz substrate.

The value of the pressure can be found from the measured frequency difference $|f_x - f_y|$. The sensitivity of $|f_x - f_y|$ to pressure usually also depends on temperature. Knowing this dependence from calibration data and having found the temperature from $|f_x - f_z|$ allows full temperature compensation of the measured pressure to be achieved without a need of solving non-linear algebraic equations.

The substrate 7 is supported by the base 2 and for convenience may be secured to the base by means of a flexible adhesive. If adhesive is used to secure the substrate in position, the flexibility of the adhesive should be such that the respective end regions 8,9 of the substrate 7 are free to move as substrate 7 is acted upon by a projection 10 formed integrally with or secured to the lid 5. Accordingly the end regions 8,9 will be substantially unstrained even when the central region is strained as a result of movement of the diaphragm.

The lid 5 is provided, in the centre of the major surface 5A, with a projection 10 formed by a dimple pressed in the material of the lid. The position of the projection 10 is shown in broken line in Figure 1A. The projection 10 is able to exert a downward force (as viewed in Fig 1B) at the centre of the substrate, but is unable to exert a force on ends 8,9.

Suitable antennae are provided for receiving an excitation signal for each of the SAW devices X, Y, Z and for transmitting a response signal from each of the SAW devices. The antennae may be located on the exterior of the container 4 in which case appropriate electrical connections must be provided extending through the material of the container 4. Alternatively, it may be possible to lay the antennae down as tracks on the interior surface of the container 4 or on suitable areas of the substrate 7 not occupied by the SAW devices themselves.

In use, a pressure monitor as described above is placed within a zone the pressure of which is to be monitored. The pressure monitor is chosen in light of the pressures to which it is intended to be sensitive, and in particular, the absolute pressure sealed within the chamber 6 is chosen so that the diaphragm is deflected towards the base 3B by the pressure prevailing in the region to which the device is sensitive. This deflection of the diaphragm will cause bending of the substrate 7 only between the edges 11,12 of the frame 3A and accordingly a change in the resonant frequency of the central SAW device Y. The resonant frequency of the SAW devices may be determined by known techniques to calibrate the monitoring device.

If there is a change in pressure in the zone surrounding the device this will result in a movement of the lid 5 acting as a diaphragm. An increase in pressure will

result in movement of the diaphragm towards the base 3B and a reduction in pressure will cause a movement of the diaphragm away from the base 3B. Either change will result in a change in the bending of the substrate 7 with a resultant change in the resonant frequency of the central SAW device Y. By monitoring the changes in resonant frequency of the SAW devices an indication may be provided of the change in pressure. The device may, for example, be located within a vehicle tyre to provide a remote indication of a loss of pressure within the vehicle tyre.

The embodiment of Figure 1 is particularly desirable in that one substrate 7 is provided and accordingly SAW devices may be provided on one surface only.

It will be noted that the above described embodiment of the invention is particularly simple to fabricate and comprises in essence, only four elements, namely the base 2, the substrate 7 (with its associated SAW devices), the lid 5 and appropriate antennae (not shown). Furthermore, the device may be constructed using three identical SAW devices, the different characteristics of the Y and Z devices being achieved by their different orientations. The components may be assembled under factory conditions by means of a simple and logical progression, namely the antennae may be laid down as suitable tracks on the base 2 and connected to the antennae, and finally the lid 5 may be secured to the base to complete the unit. The simple assembly techniques offer substantial practical advantages for a mass produced unit to be used in relatively low cost applications such as monitoring the pressure within vehicle tyres. The unit, once produced, is completely self-contained and merely requires to be secured in position. Securing the unit in position may be effected by semi skilled or unskilled labour within a factory environment.

In the second embodiment of Figure 2 two substrates 20,21 are provided instead of the single substrate 7 of Figure 1, and at least two SAW devices are provided on the lower unstrained substrate 21, one of which is inclined relative to the other as in the first embodiment. In other respects, the components in operation of the embodiment of Figures 2 are substantially the same as those of the embodiment of Figure 1. As in the case of the embodiment of Figure 1, the substrates 20,21 may

conveniently be held in position by means of flexible adhesive.

In the third embodiment (Figure 3) a two substrates 30,31 are provided and two SAW devices are provided on opposite sides of the upper strained substrate 30. In other respects, the components in operation of the embodiment of Figure 3 are the same as those of the embodiment of Figure 2, that is a third SAW device is provided on the unstained substrate at an inclined angle to at least one of said strained devices so as to enable both pressure and temperature readings to be taken.

Referring now to Figures 4, a further embodiment of the invention is shown. As in the case of the embodiment of Figures 1-3 the device comprises a container 4 which is of ceramic or metal material. The container 4 comprises a rigid frame 3A and a base B. The open mouth of the container is closed by a lid 5 acting as a diaphragm to define a hermetically sealed chamber 6. In the case of this embodiment a SAW device substrate 40 to detect changes in deflection of the diaphragm 5 is secured to the diaphragm itself. To this end, pressed indentations 42,43 are provided in the diaphragm. The indentations 42,43 define ridges within the chamber 6 to which the substrate 40 is secured, for example by soldering. The substrate 40 has mounted thereon one or more SAW devices. A further substrate 41 is mounted on the unstrained area of the chamber 6 and carries at least two further SAW devices such that pressure and temperature monitoring capabilities are provided.

In the case of embodiments of Figures 4, deformation of the lid 5 acting as a diaphragm caused by pressure changes will result directly in deformation of the substrate, 40 with a resulting change in the resonant frequency of the SAW devices mounted thereon. Antennae for the SAW devices may be provided by any convenient means, for example electrically conducted track provided on the surface of the container 4 or electrical connections to external antennae passing through the container 4.

Figures 5A and 5B show a further embodiment of the invention in which the three SAW devices X,Y,Z are mounted on a single substrate 50 which is attached to the base 2 at only one end so as to form a cantilever which is engaged by the

projection 10 on the diaphragm at a point part way along the length of the substrate. One of the SAW devices Y is mounted on the cantilever substrate between the supported end and the point of engagement of the projection 10 whilst the other two X,Z are mounted between the point of engagement of the projection 10 and the free end of the cantilever as shown in Figure 5A. As with the earlier embodiments, the third SAW device Z is inclined to the second X so as to achieve a differential temperature characteristic.

Loading of the substrate by the projection causes strain in the first portion of the substrate between the supported end and the point of engagement of the projections, thereby causing a pressure response in the first SAW device (Y). The second portion of the substrate between the point of engagement of the projection 10 and the free end of the substrate is, however, not strained and provides a reference region - any changes in the characteristics of the two SAW devices X,Z mounted thereon being as a result of temperature changes only.

Figures 6A and 6B show a variation of the embodiment of Figures 5A and 5B in which the substrate is again attached to the base 2 at one end only but is also now supported at its middle by support 61 so as to split the substrate into two sections, a first beam section which extends between the base mount and the support 61 on which is mounted a first SAW device Y, and a second cantilever section which is formed by the portion of substrate which overhangs the support 61 and on which is mounted second (X) and third (Z) SAW devices. As with the previous embodiments, the third device (Z) is inclined to the second (X) as shown in Figure 6A. The projection 10 on the diaphragm is then positioned to engage the beam section of the substrate, which constitutes a deformable substrate, causing straining of the first SAW device Y only upon deflecting of the diaphragm. The provision of the support 61 will cause the cantilever section to deflect upwards upon the projection 10 engaging the substrate but to remain unstrained so as to provide a reference region. In other respects, the operation of the embodiments of Figures 5 and 6 are the same as for the previously described embodiments. It will, of course, be understood that the second and third

SAW devices X,Z in the embodiments of Figures 5 and 6 may be mounted in the opposite way around to the positions shown in the drawings.

CLAIMS:

1. A pressure monitor comprising a base having a rigid frame; a lid secured to the base to define with the base a substantially fluid tight chamber, at least part of the lid being flexible and forming a diaphragm which will deflect in response to changes in the fluid pressure surrounding the monitor; means remote from the edge of the frame for transmitting movement of the diaphragm to a distortable substrate located within the chamber, the distortable substrate having a first SAW device mounted thereon, and at least a second and a third SAW device mounted within the chamber, said second SAW device being carried on a reference substrate section and having its direction of propagation inclined at an angle to the direction of propagation of at least one of said first and third SAW devices, wherein movement of the diaphragm induced by a change in pressure in the zone surrounding the monitor results in distortion of the distortable substrate, which is measurable by the SAW device mounted thereon, without distorting said reference substrate section.
2. A pressure monitor according to any of the preceding claims, wherein said distortable substrate is formed by a first region and said reference substrate section by a second region of a single substrate.
3. A pressure monitor according to claim 2, wherein said single substrate takes the form on a cantilever which is supported at one end on the base, and is engaged by the movement transmitting means at a point partially along its length, said first region being the section of the substrate between the base support and the point of engagement of the movement transmitting means and said second region being the section of the substrate between the point of engagement of the movement transmitting means and the free end of the substrate.

4. A pressure monitor according to claim 2, wherein the single substrate takes the form of a beam which is supported at one end on the base by a first support member and is supported at a point partially along its length by a second support member, said first region being formed by the section of the substrate between said first and second support members and said second region being formed by the section of the substrate which projects beyond said second support member, the movement transmitting means engaging said first region.
5. A pressure monitor according to any of the preceding claims, wherein said first SAW device has a direction of propagation which is parallel to the direction of propagation of said third SAW device.
6. A pressure monitor according to any of the preceding claims, wherein each of said SAW devices is a SAW resonator.
7. A pressure monitor according to any of the preceding claims, wherein each of said SAW devices has a different resonant frequency.
8. A pressure monitor according to any of the preceding claims, wherein said second SAW device is oriented with its directions of propagation inclined at an angle in the range of 10-30° to said third SAW device.
9. A pressure monitor according to any of the preceding claims, wherein said second SAW device is oriented with its directions of propagation inclined at an angle in the range of 16-20° to said third SAW device.
10. A pressure monitor according to any of the preceding claims, wherein said second SAW device is oriented with its directions of propagation inclined at an angle

of 18° to said third SAW device.

11. A pressure monitor according to any of the preceding claims, wherein all of the SAW devices are located on the same side of a single substrate.

12. A pressure monitor according to any of claims 1 to 10, wherein said SAW devices are distributed on both sides of a single substrate.

13. A pressure monitor according to claim 1 wherein said third SAW device is mounted on said non-distortable substrate section.

14. A pressure monitor according to claim 1, wherein said third SAW device is mounted on the opposite side of said distortable substrate to said first SAW device.

15. Any of the pressure monitors substantially as herein described with reference to the accompanying drawings.